

ESD TR-68-232
ESTI FILE COPY

ESD-TR-68-232

ESD ACCESSION LIST

ESTI Call No. 62195

Copy No. 1 of 2 ESE

ESD RECORD COPY

RETURN TO
SCIENTIFIC & TECHNICAL INFORMATION DIVISION
(ESTI), BUILDING 1211

Quarterly Technical Summary

General Research

15 August 1968

Prepared under Electronic Systems Division Contract AF 19(628)-5167 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts



AD675291

The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology, with the support of the U.S. Air Force under Contract AF 19(628)-5167.

This report may be reproduced to satisfy needs of U.S. Government agencies.

This document has been approved for public release and sale; its distribution is unlimited.

Non-Lincoln Recipients

PLEASE DO NOT RETURN

Permission is given to destroy this document
when it is no longer needed.

Quarterly Technical Summary

General Research

15 August 1968

Issued 11 September 1968

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts



INTRODUCTION

This Quarterly Technical Summary covers the period from 1 May through 31 July 1968. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

CONTENTS

Introduction	iii
DATA SYSTEMS – DIVISION 2	
Introduction	1
Division 2 Reports on General Research	2
Digital Computers – Group 23	3
I. Circuit and New Machine Development	3
II. Magnetic Film Engineering	4
III. System Programming	5
IV. Computer Systems	5
Computer Components – Group 24	6
I. Permalloy Films	6
II. PEBA Memory System	6
III. Electron Transport	7
Psychology – Group 25	8
I. Provision for Man-Machine Interaction on the IBM 360/67	8
II. Provisions for Man-Machine Interaction on the TX-2 Computer	10
III. Human Factors in On-Line Computation	11
IV. Human Information Processing	11
Computer Systems – Group 28	13
I. Computer Center Development	13
II. LISTAR (Lincoln Information Storage and Associative Retrieval System)	13
RADIO PHYSICS – DIVISION 3	
Introduction	15
Division 3 Reports on General Research	16
Surveillance Techniques – Group 31	18
I. Summary	18
II. Space Surveillance Techniques	18
III. Planetary Radar	18
IV. Thomson Scatter	19
V. Radiometric Techniques	20
VI. Meteorology	21

Contents

RADAR – DIVISION 4	
Introduction	23
Microwave Components – Group 46	25
I. Introduction	25
II. Diode-Using Devices	25
III. Low-Loss Waveguide Switches	26
IV. Wideband Antenna Feeds	26
V. Millimeter-WaveLength Program	26
ENGINEERING – DIVISION 7	
Introduction	27
Division 7 Reports on General Research	28
Mechanical Engineering – Group 71	29
I. Haystack Cryogenics	29
II. Solid State Research	29
III. CO ₂ Laser Radar	29
Component Design and Development – Group 73	31
Integrated Circuit Facility	31
Physical Plant Engineering – Group 75	33
I. Building E Extension (Integrated Circuit Facility)	33
II. Building J Modifications	33
Control Systems – Group 76	34
I. Haystack	34
II. Millstone Optical Tracker Complex (CO ₂ Laser Radar)	34
SOLID STATE – DIVISION 8	
Introduction	35
Division 8 Reports on General Research	37
I. Solid State Device Research	43
II. Optical Techniques and Devices	44
III. Materials Research	44
IV. Physics of Solids	45

DATA SYSTEMS DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 May through 31 July 1968 for the General Research Program of Division 2. Separate progress reports on the Re-entry Systems Program, Graphics, and Project PRESS describe other work in the Division. All the work of Groups 21 and 22 and some of the work of Groups 23, 25, 26, and 28 is therefore reported separately.

F.C. Frick
Head, Division 2
V.A. Nedzel
Associate Head

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1968

UNPUBLISHED REPORTS

Journal Articles

JA No.

3226	Hot Electron Transport in Al-Al ₂ O ₃ Triodes Produced by Plasma Oxidation	E. E. Huber F. L. Johnston C. T. Kirk	Accepted by J. Appl. Phys.
3262	The LEAP Language and Data Structure	P. D. Rovner J. A. Feldman*	Accepted by Commun. ACM
3269	Diagnosis of Single Gate Failures in Combinational Circuits	G. D. Hornbuckle R. N. Spann*	Accepted by IEEE Trans. Electron. Computers
3278-I, -II, -III	Thin Films. Part I: Introduc- tion. Part II: Magnetization Ripple. Part III. Uniaxial Anisotropy	M. S. Cohen K. J. Harte D. O. Smith	Accepted by <u>Magnetism and Magnetic Materials 1968 Digest</u> (Academic Press, New York)

Meeting Speeches[†]

MS No.

2006A, 2006B	Introduction to Data Structures	W. R. Sutherland	Computer Graphics Seminar, Trondheim, Norway, 14 - 16 May 1968; University of Michigan, 24 - 25 June 1968
2237A	Computer Assistance in the Layout of Integrated Circuit Masks	W. R. Sutherland	Computer Graphics Seminar, Trondheim, Norway, 14 - 16 May 1968
2242	Anisotropy Annealing by Diffu- sion of Interacting Defects Between Grain Boundaries in Magnetic Films	K. J. Harte D. O. Smith M. Gross*	Colloquium on Physics of Magnetic Thin Films, Irkutsk, U. S. S. R., July 1968
2312	An Introduction to Computer Graphics	W. R. Sutherland	M. I. T. -TUB Seminar, Berlin, Germany, 22 July 1968

* Author not at Lincoln Laboratory.

† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

DIGITAL COMPUTERS GROUP 23

I. CIRCUIT AND NEW MACHINE DEVELOPMENT

A. Semiconductor Processing

The flip-chip technique has been demonstrated by successfully fabricating two 9-bit parity arrays from 3-bit parity chips. Each 9-bit circuit requires the bonding of four chips which have twelve pads apiece. The wafer chip containing the interconnection pattern has an area of 200×80 mils.

The Lincoln Laboratory mask-drawing computer program has been used to generate mask sets for two devices. A subcontractor then used the masks to fabricate the two circuits, a 3-input ECL gate, and a 256-bit read-only memory.

Measurements made on various circuits with three layers of metal have shown second- to third-level vias to be geometry dependent. A via test wafer will provide the information required to formulate design rules for good vias.

B. TIC (Testing Integrated Circuits) Terminal

Programs have been written to measure the following transistor parameters: DC forward current gain, collector capacity, saturation current, series emitter and collector resistance, and h_{rb} from which base resistance can be obtained.

C. Logic Testing

As part of the computer-aided design effort for LSI processor development, we have investigated the problem of computer-generated diagnostic tests. We are especially interested in theory and methods applicable to logic circuits with more than fifty gates, where most gate outputs cannot be directly probed. To simplify testing and to satisfy our own needs, only combinational circuits were considered. Unfortunately, the literature contains no satisfactory testing methods for the broad class of failures we wished to diagnose.

The study resulted in the development of diagnostic test procedures based on a single gate failure hypothesis. We postulate that a logic circuit can be partitioned into a set of gates where failure is due to an arbitrary transformation of the correct function of any one, but only one, of the gates. A test is the application of one input combination to the input terminals and the interpretation of the response at one of the output terminals. We have developed methods for finding test sets which will detect any (detectable) single gate failure, identify the offending gate (or gates, since certain failures cause equivalent terminal behavior), and specify the function actually being generated by the faulty gate.

The bounds which have been derived for the size of the test sets are encouragingly small. If it is assumed that the circuit consists of K gates, each with m inputs, at most $K2^m + K - 1$ tests need to be applied. An alternative but equivalent procedure, requiring less computation at the time of testing, requires storage for $K^2 2^m$ tests although fewer than $(K - 1)2^{m+1}$ must be applied to the circuit being tested. The latter scheme is being implemented on the TX-2. A paper describing this new approach to testing has been submitted for publication.

II. MAGNETIC FILM ENGINEERING

A. Large Capacity Memory

1. LCM for TX-2

The one-million-bit magnetic film memory was operated with an exerciser at an access time of $0.6\mu\text{sec}$ and a cycle time of $1.2\mu\text{sec}$. Drive current margins are about ± 10 and ± 15 percent for word and digit current, respectively. Since 3 July 1968, the memory has been operating in TX-2, where it is at present computer-limited to a $2\mu\text{sec}$ cycle time. During this shakedown period, the error rate, aside from circuit failures, has been less than one per day.

2. LCM-II Digit Line Conductors

Investigations in making the 40- to 56-inch-long digit conductors have led to generation of such lines by scribing completely through the copper layer. Thus, variabilities introduced by the resist-scribe-etch process are eliminated, since no resist or etching is required. Drawbacks inherent in the scribe-only technique are the necessity to have very flat substrates (Kapton-copper) as well as imperfection-free, well-adhered copper layers. However, the edges are excellent, and line-width control is very good. Design of a special scribing machine to generate such digit sets is proceeding.

3. Digit Lines Edge Definition

Minor changes in processing techniques have produced some improvement in the edge straightness of lines photoetched with negative-working KPR. However, the use of positive-working AZ-111 photoresist has resulted in the most marked improvement in line-edge quality.

B. New Film Techniques

1. Digit Line Flux Closure

Two types of digit keepers for 0.006-inch lines on 0.010-inch centers have been studied experimentally; in both cases, the easy axis is parallel to the line. In the first case, an evaporated 6000-Å permalloy film was etched the same width as the digit line; in the second, the permalloy was 0.003 inch wider than the 0.0002-inch-thick copper conductor. Improvements in the following factors, compared with an unkeepered digit line, resulted in: (a) signal increase, (b) digit field increase per unit current, and (c) demagnetizing field reduction. For the first type of keeper, the improvement was (a) 40 percent, (b) 25 percent, and (c) 30 percent, and for the second (a) 85 percent, (b) 30 percent, and (c) 50 percent.

2. Optical B-H Looper

The magneto-optic B-H looper is operational and has been useful in resolving magnetic properties of the top and bottom films in a multilayer structure. An unwanted magneto-optic rotation was discovered in the lenses of the optical system, but it can be compensated optically.

A miniature optical looper was built using an infrared GaAs diode as the light source and a silicon photocell as the detector. The light path is about 1 cm. (The present xenon-arc system has a light path nearer 1 meter.) This looper can examine a magnetic surface 2 by 5 mm.

III. SYSTEM PROGRAMMING

A. Computerized Documentation

The problem of maintaining useful up-to-date documentation of the constantly changing TX-2 subsystems is now being approached by computerizing the documentation. A rudimentary program has been written for retrieving any of the desired documentation on the display scope, Xerox, or typewriter. Thus far, the following documentation has been computerized: descriptions of APEX calls, general TX-2 operating instructions, part of a manual on the Mark 5 assembler system, and descriptions of several public programs.

B. Circuit Simulation

Simulation of the electrical behavior of large-scale integrated (LSI) circuits has been undertaken on the assumption that the interesting computer logic of the next ten years will consist of LSI circuits. Some of the reasons favoring simulation of such circuits are:

- (1) Logical circuits are sufficiently complex that paper and pencil calculations are of limited use.
- (2) Breadboard techniques are not equal to the task of providing the "worst-case" designs required by LSI.
- (3) LSI prototype development and fabrication is expensive and time-consuming. Thus, trial and error design is precluded.

A number of circuit simulation programs already are available (e.g., NET-1, ECAP, CIRCUS, SCEPTRE) and run on such machines as the IBM 7044 and 7094. These programs are not well suited to the simulation of LSI circuits, however, because they perform reliably only for small circuits, whereas LSI circuits tend to be large. Moreover, the programs have no features for producing the worst-case designs required in LSI work.

Work to date has focused upon the problem of simulating the steady-state (or DC) behavior of logic circuits. This problem was chosen as a starting point because it is central to all circuit simulation. Moreover, reasonable DC models of solid state devices are available.

Several promising DC analysis algorithms have been identified. An experimental program employing the algorithms will be implemented in the near future.

IV. COMPUTER SYSTEMS

A. Display

The hybrid section of the conic generator has been redesigned for increased drawing speed and decreased switching noise. The new hardware will be installed in TX-2 early this fall.

B. Typewriters and Keyboards

All logic for the new console has been debugged, and the hardware has been turned over to system programmers and users. In spite of the fact that the packaging is temporary, the console seems to have met with user acceptance.

COMPUTER COMPONENTS GROUP 24

I. PERMALLOY FILMS

A. Determination of Domain Wall Shape from Lorentz Micrographs

The problem of determining the shape $\varphi(x)$ of a domain wall from the measured intensity I of a Lorentz micrograph has been solved in the low-contrast limit. The result, which is obtained by assuming a small magnetic phase shift and applying Fourier transform techniques to the wave-optical expression for the electron intensity I^* , is

$$\sin \varphi(x) = \frac{c \hbar q}{8\pi M e d Z} \int_{-\infty}^{\infty} [1 - I(x', Z)] U \left[\frac{\sqrt{\pi}}{R_L} (x - x') \right] dx'$$

where q = electron wave number, d = film thickness, Z = defocusing distance, $R_L = Z/2q$, and

$$U(\xi) = \operatorname{sgn}(\xi) \sum_{m=0}^{\infty} (-1)^m e^{-|\xi| \sqrt{m}}.$$

This formula gives a straightforward and practical method of processing experimental micrographs in order to obtain the shape of a domain wall. Experimental work currently is in progress.

B. Optical Processing of Lorentz Micrographs

The Fourier transform of a Lorentz micrograph of ripple has been taken by means of an optical diffractometer on a sample plate which we sent to Dr. J. Berger of the Roswell Park Memorial Institute, Buffalo, New York. The results show that this is a powerful method of analysis; consequently, we are building a diffractometer.

II. PEBA MEMORY SYSTEM

A. EuIG Memory Material

EuIG has been chosen as the magnetic material for initial experimental studies of the photon and electron beam accessed (PEBA) memory system for the following reasons: (1) EuIG has the largest Faraday effect of any of the REIG; (2) suitable energy levels exist for the implementation of thermal pumping. Single crystals of EuIG have been grown and will be used to verify the expected energy-level scheme. Subsequently, thermal readout of a single bit will be studied at a wavelength of $\sim 2\mu$. The required infrared apparatus for these experiments is being assembled.

B. EuIG Films

Attempts to fabricate EuIG films using RF sputtering are in progress.

* See, for example, M.S. Cohen, J. Appl. Phys. 38, 4966 (1967), DDC 668727.

C. Electron-Beam Heating

The frequency response of electron-beam heating is being studied with an apparatus which generates a 50- μ -diameter electron beam. Temperature pulses of 150° on a glass substrate at a 10-kHz rate have been measured and will be compared with theory.

D. Optical Cavity Studies

Work is in progress to evaluate the maximum electric field that can be generated in practical dielectric-film optical cavities. Cr³⁺ ions implanted in the cavity are being used as a probe of the optical field by measuring the fluorescent radiation from the ions after excitation by an optical pulse from a ruby laser.

III. ELECTRON TRANSPORT

A. Theory of Hot Electron Transport

In the preceding Quarterly Technical Summary,* we proposed to study the relaxation of a hot electron distribution, assuming that the relaxation is governed by a Boltzmann equation of the form

$$\frac{\partial f(\vec{k}, t)}{\partial t} = \frac{2}{\hbar} \frac{1}{V} \sum_{\vec{k}' > k_f} v(\vec{k} - \vec{k}') \operatorname{Im} \frac{1}{K(\vec{k} - \vec{k}'; \epsilon_{\vec{k}} - \epsilon_{\vec{k}'} + i0^+)} \left\{ \frac{f(\vec{k}', t)}{1 - \exp[-\beta(\epsilon_{\vec{k}'} - \epsilon_{\vec{k}})]} + \frac{f(\vec{k}, t)}{1 - \exp[-\beta(\epsilon_{\vec{k}} - \epsilon_{\vec{k}'})]} \right\}.$$

We have subsequently set up a Fortran program to integrate the above equation to yield $f(\vec{k}, t)$, given an arbitrary initial distribution $f(\vec{k}, 0)$ which is assumed, in the simplest case, to be spherically symmetric in \vec{k} space. Results from the program have been obtained for an electron density corresponding to that of Al. We have studied the relaxation process by choosing initial distributions sharply peaked at three different excitation energies, corresponding to 3, 6, and 9 eV above the Fermi surface. As expected from the self-energy approximation to hot electron relaxation, the lifetime of a hot electron decreases strongly with increasing energy. In the present treatment, the catastrophic nature of an electron-electron collision is reflected by a well-defined minimum in the distribution function.

We are presently continuing with these investigations for an electron density appropriate to Au, Ag, on a free electron basis.

B. Experimental Studies of Hot Electron Transport

Triode mask alignment difficulties have been solved and two new types of collector barriers have been investigated. We found it possible to prepare collectors of the form Al-AlN-Al, where the AlN was made by plasma anodization of Al in nitrogen. Evaporated silicon has also been investigated in the base-collector configuration Au-Si-Au. Both of these collectors had suitable impedance characteristics for α measurement, but no dramatic increase in α was observed over that obtained in the aluminum oxide collector.

* General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 May 1968), p. 10, DDC 670832.

PSYCHOLOGY GROUP 25

I. PROVISION FOR MAN-MACHINE INTERACTION ON THE IBM 360/67

A. Editor System

The Editor contract has concluded with the delivery of an Editor Generating System and the following three Editors.

- (1) Editor. This is a line editor, and is the most basic Editor of the system. Its procedures carry nearly all the actual editing functions for all the editors. The requests currently implemented are similar to those of the CMS EDIT command (deliberately), with minor variations and with a few significant additions, including:
 - (a) CASE turns on or off a lower- to upper-case translator for keyboard input.
 - (b) There is an input-output translation table manipulable by the user with the request SET.
 - (c) There is a buffer which the user can write into and copy from with the requests GET and PUT.
 - (d) EXECUTE effects a file of previously written edit requests from the user's disk storage space.
 - (e) The NEGATE CHARACTER negates the control function of the character immediately following it. This enables a user to use the characters @ and ¢ in script files.
- (2) HEX Editor. This is the Editor that can be most universally used; it provides an absolute capability to edit any file in the system. The changes made in any file are not limited by the character set of the terminal. For example, it is generally dangerous to print out a TEXT file with the CMS command PRINTF, because some of the characters interpreted may turn off the keyboard. HEX enables one even to alter a TEXT file.
- (3) Fortran Editor. This provides an optional syntax check of each statement, in addition to the usual editing functions of the line editor; and it provides a powerful and flexible statement formatter. Most syntax errors will cause the typing of diagnostic messages at the terminal. This helps the user to write a syntactically correct program before compilation. Few restrictions are placed on the format of a statement, and symbolic statement numbers are allowed.

The Editor Generating System (EGS) is an interactive string manipulation system that supplies the system programmer with a command language for implementing time-shared editors. The editors generated by the EGS consist of procedures which create and alter user disk files. The EGS has been implemented in Assembly Language as a self-loading module; its loading and all its I/O are done through CMS.

The EGS provides the system programmer with the ability to write procedures that can be built into Requests; furthermore, he can deal with characters by classes (e.g., see the language COMIT or the QED editor on MULTICS). All strings including the procedures themselves and the files to be edited are stored in linked-list format.

The Editors currently implemented under this contract work well but take an inordinate amount of time. This seems to be due to the excessive paging requirements that they place on the system. Some analysis has shown that the compute time for the line editor to perform a locate request, for example, is very low; but the actual time for a typical editing session may be as much as twenty times that of the EDIT command on CMS. Of course, in some cases the extra power of EDS permits the user to do things he cannot do in any other way.

The concern with the system response time with the Editor system is not an easy one to relieve. The very basic kernel functions are involved in a fundamental way with paging. Since this is inherently a procedure-oriented system, the procedures must be stored and processed as strings, each utilizing any or all of the basic assembly language functions. In addition, there is a certain amount of inefficiency due to the fact that all strings are stored as linked lists of characters; with the EDIT command, the strings are only linked line-to-line.

It is possible that rewriting certain of the kernel routines and restructuring part of the design can diminish the paging requirements and hence sharply reduce the compute and response times. Other studies will include comparisons of user requirements in the operational context of the increasingly powerful editors becoming available.

B. Mediator and Reckoner

The current Mediator provides only basic program services. This quarter was spent in designing error services and linguistic functions essential to the user. A detailed list of changes has been prepared, many of which are minor, but some resulted from a restudy of some of the Mediator functions. The changes have been incorporated in plans for the group's work and in a programming contract for an improved Mediator.

New design work has been performed on specifying the syntax of statements and the conventions for translators, such as process builders and runners, and on specifying the way in which error conditions and attention interrupts are to be fielded. As a result, a consistent design has been worked out. It should eliminate a large fraction of the typical pitfalls for the user of a system that has the mathematical generality of the Reckoner and the linguistic generality of named arrays and other services for running programs. Some of the services to the user are being recoded, and some of the essential tools, such as conversion and deconversion of numbers, are being coded.

A new design for the management of memory has been resolved under the new programming contract. The major improvement is that inactive files will be copied onto disc when the virtual memory allotted to the user is exceeded. The new design meets the requirements that the overflow be handled automatically, without intervention by the user, and that the response of the system be rapid as long as the demand does not exceed the allotment of virtual memory.

Progress has been made on providing the ARDS display for the Reckoner user. The peripheral hardware has been tested and debugged. An algorithm for display of graphs has been specified and has been tested by implementing it as a process on the current TX-2 Reckoner.

II. PROVISIONS FOR MAN-MACHINE INTERACTION ON THE TX-2 COMPUTER

A. APEX

During the past quarter, the APEX time-sharing system on the TX-2 computer has been modified to accommodate a storage-tube display and to allow all requests for outputs to be trapped to a program provided by the user.

The display routines allow information to appear on the Tektronix Model 611 storage scope. They allow the scope to be used as a normal refreshed display, as a storage display, or as a combination display in which part of the information is stored and part refreshed. The latter mode is of particular interest in many applications where only a small part of the picture need be handled in an interactive fashion. These new display routines represent a departure from the concept of a list-structured display file, which is used in the refreshed display in the APEX system. List-structured display files are advantageous in interactive applications for which a storage display is inappropriate. By using a simple linear format, the overhead associated with the stored display has been significantly reduced. It is likely that, eventually, storage displays will become the primary displays at all consoles.

The human-factor experiments described in Sec. III require that console outputs be delayed for arbitrary periods of time. Since outputs are generated by many different programs, modifying all the programs to accommodate the delay requirements would be a large task. Because all outputs are generated via supervisor calls to APEX, changing APEX would be simpler; but even this change would involve considerable programming effort, and the writers of new output routines would have to be concerned with providing for the case where outputs are delayed. The solution that was chosen makes use of the extra bit (the meta-bit) in the memory word and the trapping hardware on TX-2. Meta-bit traps are placed on the registers of the call dispatch table in the APEX system. When such a trap occurs, the user program that gave the call is interrupted, and control is passed to another user-mode program, which removes the traps, waits out the specified delays, and then causes the original program to resume. Only one delaying routine is needed, and if new output calls are added to the system, the only change required is an addition to the list of calls to be trapped.

The call-trapping feature is not limited to delaying outputs; it is available for other applications since the program which responds to the trap is an arbitrary user program. Debugging is another promising application.

During the past quarter, 25,600 registers of experimental large-capacity memory (LCM) were made available to the time-sharing system. As expected, the additional memory reduces the need for swapping, and thus makes a noticeable improvement in the performance of the time-sharing system under heavy load. This reinforces the conclusion that a moderate increase in main memory can have disproportionate effects on the performance of the system.

B. Lincoln Reckoner

Specifications have been drawn up for a small interpreter that will accept statements in the language of matrix algebra and will perform the appropriate computations by calling on the matrix programs in the Reckoner library. One of the reasons for installing this interpreter is to get practical experience with the way that translators of this kind should report error conditions to the user who is not a programmer.

III. HUMAN FACTORS IN ON-LINE COMPUTATION

As reported in the last Quarterly Technical Summary,* a long-range program of research on human factors in on-line computation has been undertaken. The objective is to provide data that can be used in the design of computational facilities for on-line problem solving. The first series of experiments, now in progress, is concerned with the delay in the machine's response: the experiments are intended to yield curves showing how the time that the user requires to complete a task depends on the speed with which the machine responds to his commands. Given those data, and given the tradeoff between the cost of the user's time and the cost of speeding up the system, a system designer can determine whether it is profitable to speed up the machine's response.

The experiments are being done with the Lincoln Reckoner, an on-line computational service that works in the environment of the APEX time-sharing system on the TX-2 computer. APEX has been modified so that any output request may be trapped to a program that conducts the experiment. This program decides how the output requests should be delayed, and it records the user's commands.

Two experiments have been completed during this reporting period. In the first, the subjects used the computer to solve a series of problems about simple networks. In each problem, the network had two inputs, one output, and three "black boxes" that intervened between the inputs and the output: the subject was given the inputs and the output, and was required to select, from a restricted list of possibilities, the mathematical functions that had to be put into the "black boxes" to produce the given output. In the second experiment, the subjects were given a series of tasks chosen to be similar to the tasks a scientist or engineer performs when he is actually using the Reckoner. An attempt was made to pick tasks that would (a) be realistic without requiring specialized training in particular branches of science or engineering, (b) be short enough to complete in a few minutes if the responses of the machine were not delayed, and (c) have a clear-cut criterion of completion, so that the subject would know he had finished and could proceed to the next task. As expected, a considerable amount of trial and error was needed to define both kinds of tasks. For the present, the most important conclusion from these experiments is that the tasks were specified well enough to produce stable results.

The experiments also yielded data that could, in principle, be used in the design of on-line computational services; however, further experiments should be done before any attempt is made to put the data to practical use. For example, in all three of the experiments performed thus far, the delay in the computer's response was almost constant; that is, in a condition where the nominal delay was 100 sec, the actual delay was always 100 sec plus or minus a few percent. A more realistic distribution of delays must be investigated.

IV. HUMAN INFORMATION PROCESSING

A. Decision Making Near the Visual Threshold

A versatile set of equipment has been constructed for experiments on binary decisions in the detection of low-intensity flashes of light. The apparatus is automatic enough so that the presence of an experimenter is not required during experimental sessions: the presentation and timing of

* General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 May 1968), p. 12, DDC 670832.

Division 2

the stimuli is controlled by paper tape, and the responses and their latencies are recorded automatically.

The equipment will be used in a series of experiments on the relation between the frequency with which the subject detects a stimulus, and the time required for him to make his decision. Of particular interest is the way in which those two measures of behavior are affected by the temporal distribution of the light energy in the stimulus.* In the first experiment, now in progress, the stimulus consists of two successive flashes.

* M. Grossberg, "The Latency of Response in Relation to Bloch's Law at Threshold," *Perception and Psychophysics* (1968), in press.

COMPUTER SYSTEMS GROUP 28

I. COMPUTER CENTER DEVELOPMENT

Early in this quarter, two changes were made in CP/CMS time-sharing operations that resulted in a substantial performance improvement. First, the normal hardware configuration was altered to include the second drum for page swapping. Although this meant some degradation in the performance of the batch monitor which operates in parallel, there was a substantial net gain.

Second, the more important change was to the CP scheduling algorithm which determines who will get the next time quantum. The new algorithm separates users into two broad categories based on their present activity in the system: the first group, which receives preferential treatment, consists of those who require conversational response at their terminal; the second group comprises those who require other resources of the system, but are not carrying on a "conversation." Users move from one group to the other as their activity changes moment by moment from editing, to compiling, to execution, and back again. Within each group, a user shuttles from active to inactive status depending on the progress of his task and the amount of active time accumulated or shared with others.

The external effect of these changes has been a significant improvement in the service to a conversational user, with a lesser improvement for other users. This permitted lifting the old experimental limit of eighteen simultaneous users up to the hardware limit of thirty-one.

Although work is in progress on a "data concentrator" which will overcome this limit and handle a larger number of communications lines, a practical limit for the number of simultaneous users on a single CPU system is imminent. During the next quarter, some attention will be focused on determining what this limit is, and working out operational methods of distributing the services of this system to all potential users.

The implementation of a new version of the batch monitor, IBM's Operating System/360 - Version 14, has been very disappointing. Many of the major components of this system failed to operate satisfactorily during testing. In particular, the new Fortran H compiler, which we hoped would be closely compatible with the Fortran G compiler used in CP/CMS, is unusable. In place of the entire new version, some of the tested and improved components will be added to the current system.

II. LISTAR (Lincoln Information Storage and Associative Retrieval System)

Over the past quarter, programs for searching files were completed and tested. Programs have also been completed which permit a user to issue simple English commands to LISTAR for carrying out a search of a file of his choosing. The command language is conversational, responding to user errors with corrective instructions, and allowing the user to specify the typing format of the response to his query.

RADIO PHYSICS DIVISION 3

INTRODUCTION

This section summarizes the General Research efforts of Division 3 for the period 1 May through 31 July 1968. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semiannual Technical Summary and the Quarterly Letter Report to ARPA.

S. H. Dodd
Head, Division 3

M. A. Herlin
Associate Head

DIVISION 3 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1968

PUBLISHED REPORTS

Journal Articles*

JA No.

3102	Observations of 8-GHz Continuum and Hydrogen Recombination Lines in the Orion Nebula	M. A. Gordon M. L. Meeks	Astrophys. J. <u>152</u> , 417 (1968)
3116	Aperture Synthesis in Radar Astronomy and Some Applications to Lunar and Planetary Studies	T. Hagfors B. Nanni K. Stone	Radio Sci. <u>3</u> , 491 (1968)
3138	Sunrise Behavior of the F Layer at Midlatitudes	J. V. Evans	J. Geophys. Res. <u>73</u> , 3489 (1968)
3141	A Radar Study of the Lunar Crater Tycho at 3.8-cm and 70-cm Wavelengths	G. H. Pettengill T. W. Thompson [†]	Icarus <u>8</u> , 457 (1968)
3168	Discrepancies Between Radar Data and the Lunar Ephemeris	C. R. Smith [†] G. H. Pettengill I. I. Shapiro [‡] F. S. Weinstein	Science <u>160</u> , 876 (1968)
3198	Absorption of Radar Signals by the Atmosphere of Venus	J. V. Evans R. P. Ingalls	J. Atmos. Sci. <u>25</u> , 555 (1968)
3214	Indirect Experimental Evidence for the Existence of Hall and Pedersen Currents in the Auroral E-Region	R. E. Newell [†] W. G. Abel	Nature <u>218</u> , 454 (1968)
3243	Fourth Test of General Relativity: Preliminary Results	I. I. Shapiro [‡] G. H. Pettengill M. E. Ash [‡] M. L. Stone W. B. Smith [‡] R. P. Ingalls R. A. Brockelman	Phys. Rev. Letters <u>20</u> , 1265 (1968)

* Reprints available.

[†] Author not at Lincoln Laboratory.

[‡] Division 6.

JA No.

- | | | | |
|------|---|---|---------------------------------------|
| 3245 | The Case for the Radar Radius of Venus | M. E. Ash*
D. B. Campbell†
R. B. Dyce†
R. P. Ingalls
R. Jurgens†
G. H. Pettengill
I. I. Shapiro*
M. A. Slade†
W. B. Smith*
T. W. Thompson† | Science <u>160</u> , 985 (1968) |
| 3259 | The Structure of the OH Source in W3 | J. M. Moran†
B. F. Burke†
A. H. Barrett†
A. E. E. Rogers
J. C. Carter
J. A. Ball
D. D. Cudaback† | Astrophys. J. <u>152</u> , L97 (1968) |
| 3263 | Classification of OH Radio Emission Sources | J. A. Ball
D. H. Staclin† | Astrophys. J. <u>153</u> , L41 (1968) |

* * * * *

UNPUBLISHED REPORTS

Journal Article

JA No.

- | | | | |
|------|--|--|--|
| 3290 | The Pointing Calibration of the Haystack Antenna | M. L. Meeks
J. A. Ball
A. B. Hull† | Accepted by IEEE Trans. Antennas Propag. |
|------|--|--|--|

Meeting Speech‡

MS No.

- | | | | |
|-------|---|-------------|--|
| 2311A | Imaging Radio Sources with a Digital Computer | M. L. Meeks | Colloquium, Arecibo Ionospheric Observatory, Arecibo, Puerto Rico, 24 May 1968 |
|-------|---|-------------|--|

* Division 6.

† Author not at Lincoln Laboratory.

‡ Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

SURVEILLANCE TECHNIQUES

GROUP 31

I. SUMMARY

Group 31 operates and maintains Lincoln Laboratory's Millstone and Haystack radio/radar research facilities.

At Millstone, work has continued in improving the accuracy and experimental flexibility of the instrumentation. Ionospheric and auroral studies also continued, while special preparations were made for a forthcoming intensive series of DoD-requested precipitation studies which will involve both the Millstone radar and the Haystack radiometers.

Haystack endeavors were highlighted by observations centered on an inferior conjunction of Mercury, a superior conjunction of Venus, and the close passage of the planetoid Icarus. Icarus was successfully observed by radar for the first time. The rerigged Haystack antenna has also been shown to be an effective instrument at frequencies up to 35,000 MHz. Modifications to the Haystack radar were begun which will make possible the dual-polarization mapping of the moon specified in a new contract with NASA Manned Spacecraft Center.

II. SPACE SURVEILLANCE TECHNIQUES

A. Tracking Studies

In anticipation of possible experimental studies of refraction and other propagation phenomena as they affect precise tracking, the upgrading of the L-band tracking system continued. Conversion of most of the receiver system to solid state components is complete, and careful subsystem gain and stability measurements are in progress.

Other than the above activities, the tracking configuration has not been extensively used since the end of May, when the MITRE-Millstone three-station satellite-tracking interferometer program was terminated due to lack of funds.

B. Auroral Studies

No further auroral data were gathered with the L-band radar during this reporting period. Several computer programs for use in analysis of auroral data have been completed. Data taken during January, February, and March 1968 are being analyzed.

III. PLANETARY RADAR

A. Lunar Studies

Contract NAS 9-7830 with NASA Manned Spacecraft Center calls for mapping the entire lunar surface with the Haystack range-doppler radar system at a wavelength of 3.8 cm. The work is presently directed toward completing a dual-channel receiving system that will permit simultaneous reception of the polarized and depolarized components of the radar echo. It is expected that all portions of the dual-channel system will be ready to support observations in early 1969.

Work this quarter has centered on the construction of a dual-channel X-band maser pre-amplifier assembly. The maser packages themselves are on hand, and one has been tested satisfactorily in a single temporary dewar. Larger dewars have been procured for the dual maser, and the waveguide header to connect the masers to the antenna and receiver channels has been fabricated and tested both electrically and thermally.

The moon work is being reported more fully in a continuing Lincoln Laboratory Quarterly Progress Report series entitled "Radar Studies of the Moon."

B. Planetary Studies

The Planetary Radar (PR) Box was mounted on the Haystack antenna during most of the present reporting period in order to take advantage of three astronomical events: the close approach of the planetoid Icarus on 15 June, the close approach of Mercury on 17 June, and the superior conjunction of Venus on 20 June. Despite the near simultaneous occurrence of these events, useful observations were obtained of all the targets near these dates.

A modification of the planetary radar system was required to allow efficient operation against Icarus where the echo round-trip delay was only about 40 sec near close approach. Following the modification, about 48 total hours of operation were realized (many additional hours were taken which were rendered useless by rain). Echoes were obtained (for the first time) from which it will be possible to deduce the scattering properties of this planetoid.

Radar observations of Mercury at its close approach have allowed a verification of the 59-day rotation period previously obtained, as well as an improved determination of its scattering law. Further accurate measurements of the round-trip echo delay times were also obtained permitting continued improvement of its orbit. A small number of delay measurements to the planet Venus were also possible following its superior conjunction. These measurements will serve to verify further the gravitational retardation of electromagnetic propagation – a test of the general theory of relativity whose applicability has already been demonstrated using Haystack-derived Mercury echoes.

IV. THOMSON SCATTER

Regular UHF and L-band Thomson scatter operations were suspended in June for four weeks during which time the transition to operating with a new REal Time spectrum Analyzer System (RETIAS) was made. Early runs with RETIAS have disclosed a number of defects, and extensive efforts have been made to remedy them.

RETIAS will provide for the following types of runs:

Mode	Pulse Length (μ sec)	Sample Spacing (μ sec)	Range Delays Examined (msec)
A	100	50	None
B	500	200	1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5
C	1000	200	3.0, 3.5, 4.0, 4.5, 5.0, 6.0, 7.0, 7.5
D	2000	200	6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10.0, 10.5

Division 3

The A-mode runs serve to establish the shape of the electron density profile at low altitudes (≤ 300 km), and the remainder give the shape and temperatures at high altitudes. The large range of echo power encountered at successive delays in any one mode requires that the spectrum analyzer portion have a large dynamic range.

Studies of the plasma line have continued during this report period with special emphasis on dawn and sunset effects. At small frequency offsets (~ 4 MHz), the photoelectrons responsible for the plasma line have energies of about 6 eV, and both up- and down-going streams appear to have been produced locally. Additional measurements have been conducted to examine the intensity of lines associated with electrons of higher energy in the hope of detecting effects of conjugate sunset (i.e., a diminution of the down-going stream).

Six attempts were made to measure plasma drifts using the old spectrum analyzer. An analysis of the accuracy with which the spectrum center can be located suggests that after 15 minutes of observation, the error should be of the order of ± 20 Hz. In practice, however, the uncertainty appears to be more nearly ± 70 Hz, and on only one occasion were systematic offsets detectable. Preliminary analysis of measurements made using RETIAS look promising in that this system appears to perform closer to the theoretical limit.

V. RADIOMETRIC TECHNIQUES

A. Instrumentation

A major aim of the radiometry program is the development of improved means of evaluating and calibrating antenna systems. The Haystack antenna, "rerigged" late last year, has now been re-evaluated at all available operating frequencies from 1.6 through 15.5 GHz (2 cm), where a 40-percent improvement in antenna gain was noted. A test of the hoped-for capability at 35 GHz (8 mm) came when a superheterodyne radiometer operating at this frequency was installed on the antenna for a two-week period. With the participation of engineers from NASA Electronics Research Center in Cambridge, Massachusetts, who provided the radiometer, measurements were made on the sun and the planet Jupiter.

Whereas prior to the surface readjustment (rerigging) the antenna would not form a beam at 35 GHz, the above measurements revealed a well-formed beam of nearly circular cross section. A half-power beamwidth of about 1 minute of arc and an effective aperture of about 100 square meters were obtained, giving a highly unusual millimeter wave observing capability.

Interest in a search for the 23.5-GHz spectral line of ammonia has motivated a cooperative project in which NASA Electronics Research Center will provide a radiometer at that frequency for a joint NASA/Haystack observing program. This radiometer is currently being built.

M.I.T. graduate students working at Haystack have renovated two of the old 8-GHz paramps from the obsolete Haystack Radar-Communications Box. One has been packaged for use on the 140-foot antenna at the National Radio Astronomy Observatory at Green Bank, West Virginia, and the other has been incorporated into the Haystack Radiometer Box (R-Box). Both these antennas will be used in a very long baseline interferometer experiment this October.

A summer staff member is developing L- and X-band phase-locked oscillators that can be tuned within milliseconds to any frequency within their tuning range (50 percent at L-band; 10 percent at X-band). These will become part of future long baseline interferometer and spectral line systems.

Group 31 designed and constructed, for the ALTAIR system of Project PRESS on Roi-Namur, equipment to convert the ALTAIR UHF and VHF receivers to switched (Dicke) radiometers for the purpose of radiometric antenna gain and pointing calibration using known radio sources. Three radiometer channels can be run simultaneously. A Group 31 engineer visited Roi-Namur in June to help install the equipment and assist with initial tests. Antenna mechanical problems prevented measurements at that time, but since then good test data have been obtained using a number of radio sources.

B. Radio Astronomy

Immediately following announcement of the discovery of pulsars (low-frequency pulsating radio sources), we mapped the region around CP 1919, the pulsar with precisely known position, in an attempt to find continuum emission. The map was made at 8 GHz and covered a region 0.10° by 0.06° in right ascension and declination, respectively. We found no signal, although the system could have detected a point source with intensity no more than 0.2 flux units (mks).

Three programs of radiometric observation described in previous reports are continuing. Observations of 18-cm OH emission sources were continued, mostly with the Millstone antenna and the Haystack data-processing system connected through the intersite cables. The regions around these sources (W28, W43, W44, W49, W51, W75, and NGC6334) were also mapped with the Haystack antenna at 8 and 15.5 GHz. Monitoring of the variable extra-galactic radio sources (quasars and peculiar galaxies) was also continued at the above frequencies.

VI. METEOROLOGY

This portion of the Station program is under the direction of Robert K. Crane of the Space Communications Division and is a cooperative effort which serves the Laboratory's Space Communications program as well as Radio Physics.

A. Rain Observations

Two sets of rain observations were made using the Millstone L-band radar system. These measurements will be used to study the spatial scales over which rainfall intensity varies.

The data processing for last summer's measurements of rain using both the Millstone L-band radar and the 8-GHz radiometer in the Haystack PR Box is essentially complete. The results show agreement between measured values of sky temperature and estimated values based upon the radar data. The agreement shows that the postulates used to compute attenuation due to rain based upon radar measurements are correct.

B. Clear-Air Observations

Measurements of clear-air turbulence using the Millstone L-band radar were continued for comparison with X-band bistatic scattering measurements using a transmitter at Wallops Island, Virginia, and a receiver at the Westford Communications Terminal. The measurements were also for comparison with pilot observations during a series of U-2 aircraft flights.

Bistatic scattering measurements indicate that the primary cause of long-distance microwave troposcatter propagation is scattering from thin turbulent layers at or above the tropopause. The data also show that the frequency of occurrence of the thin scattering layers increases in the summertime.

Division 3

Five flights were made by the U-2 aircraft for the purpose of detecting clear-air turbulence that affects the aircraft at the height of the thin scattering layers detected by the radar. During the series of flights, the aircraft detected 23 layers characterized as "very light" turbulence, 4 layers as "light" turbulence, and 1 layer as "moderate" turbulence. The nearly simultaneous radar measurements detected the moderately turbulent layer, three of the light turbulent layers, and five of the very light turbulent layers.

RADAR DIVISION 4

INTRODUCTION

All the General Research activities in Division 4 are carried out in Group 46 and are summarized for the period 1 May through 31 July 1968. Various microwave devices and experimental millimeter radar systems constitute the principal areas of work. The major activities of the Division are in the RDT, PRESS, and RSP programs, which are reported on separately.

J. Freedman
Head, Division 4

H. G. Weiss
Associate Head

MICROWAVE COMPONENTS

GROUP 46

I. INTRODUCTION

Group 46 contributes to the radar program through direct participation in specific projects, and through a program of general research which is closely related to the microwave needs of the Laboratory. Contributions are made to the General Research Program through the study of the problems of solid-state diode-using devices, the development of techniques for computer design of microwave devices, studies of very-high-gain antennas and antenna feeds, operation of a high-power microwave laboratory, and participation in a millimeter-wavelength program.

II. DIODE-USING DEVICES

A. Diode Measurements

Investigation of measurement errors in the 30-inch-diameter, radial-line cavity disclosed two major sources of difficulty. The first is due to deviations from flatness and imperfections in the surface of the cavity. These flaws cause the resonant frequencies to differ from those predicted on the basis of a smooth, flat surface. This problem is one of fabricating technique. We believe that the difficulty can be overcome in the future by making the cavity of thick aluminum rather than thin copper, and by using a smaller diameter – perhaps 24 instead of 30 inches.

The more serious error is caused by relatively large reflections in the series of waveguide-to-coax adapters used. These reflections detune the desired resonances excessively, especially over the frequency range where the diode reactance is low. An investigation is being made of the possibility of resistive decoupling and of transmission rather than reflection measurements to minimize this problem.

B. Power Combiners

The 15-diode, power-combining doubler is under construction, and an order has been placed for the integral, multiple-diode columns to be used in this power combiner. Additional design work is being done on the 35-diode, power-combining doubler which uses a diode array imposed on an equiphase surface of a radial transmission line.

C. Low-Noise Balanced-Diode Mixers

The performance characteristics of Schottky Barrier mixer diodes, which have been purchased from various diode manufacturers, are being determined so that matched pairs might be found. The new diode test jig for use with the 1-MHz capacitance bridge has been completed, and a preliminary determination of package capacitance C_p , junction capacitance C_j , and spreading resistance R_s has been made on approximately 60 diodes.

A new diode test jig has been fabricated for the measurement of diode characteristics at 3 GHz using a modified Mavaddat technique. These measurements are now under way. In addition, a diode mount is being designed for the characterization of diodes at 10 GHz.

A theoretical study of the dispersive properties of microstrip has been initiated and is continuing at the present time.

III. LOW-LOSS WAVEGUIDE SWITCHES

During the measurement of certain waveguide switches used in the Haystack Planetary Radar Box receiving system, it was found that although the insertion loss was satisfactory over the required frequency range, the insertion loss rose sharply to a peak outside the band of interest. In order to understand this behavior, an analysis was carried out using a simplified model. Good agreement was obtained with the measured data as the rotor-to-stator gap spacing was varied.

IV. WIDEBAND ANTENNA FEEDS

Preliminary tests of a rectangular multimode horn showed equal principal-plane beamwidths at 5 and 8 GHz. At the lower frequency, the horn operates as a single-mode device; at the higher frequency, higher order modes help produce the correct beamwidth, as well as sidelobes that are down 35 to 40 dB. These higher order modes cause some problems in the 45° planes, where the beamwidth is 15 percent too narrow and the sidelobes are only down 23 dB. The cross polarization is down 26 dB. Further effort will be required to improve the patterns in the 45° planes.

Measurements on a circular horn with closely spaced circumferential slots on the internal walls showed a disappointing performance. The required slot depth appeared to be $\lambda/4$ or greater, and the bandwidth was rather poor. The slots have a considerable effect on the E-plane patterns; there, the beamwidth could be greatly widened, while the sidelobes were reduced to very low levels. Additional study is required to determine the potential bandwidth of this structure and to obtain sufficient control over the E-plane beamwidth and sidelobe level.

V. MILLIMETER-WAVELENGTH PROGRAM

The 35-GHz lunar radar has been shut down for two months for installation of dual-polarization plumbing and two receiver chains so that circular polarization can be transmitted and both circular polarizations can be received. Duplexing is achieved by means of mechanical waveguide switches. These are commercial units that have given much trouble, but now seem to be in a satisfactory state.

The automatic Doppler compensation is installed but has not yet been put into working order.

A puzzling phenomenon observed in April is now, we believe, understood. At 5 a.m. on 12 April, after receiving lunar echoes for about 6 hours, the boresighting was checked and found to have changed since the previous check at 10 p.m. on 11 April. However, at 3 p.m. on 12 April the boresighting was back where it belonged. At the time, we feared that the waveguide feed had been distorted by RF heating, with consequent shift of the beam. It now seems fairly certain that the phenomenon was an atmospheric one, rendering invalid the assumption that millimeter and optical waves undergo the same amount of refraction. The millimeter beam arrived from an angle of elevation of 0.030°, instead of the usual 0.23°. This difference is one beamwidth. Presumably, the anomalous refraction was negligible at elevations of a few degrees or more. For a ground-to-ground link using two 28-foot dishes in fixed positions separated by 6 statute miles (the length of our antenna range), the drop in signal would have been 15 to 20 dB.

ENGINEERING DIVISION 7

INTRODUCTION

The Engineering Division has supported the General Research Program of the Laboratory principally by work on the CO₂ laser radar, by modifications to Building J, by an extension to Building E to provide space for key elements of the Integrated Circuit Facility, and by utilization of the Integrated Circuit Facility to develop prototype hybrid circuits and improved fabrication techniques. Building J modifications include a 6000-square-foot addition to the existing building. The extension to Building E will eventually contain two vertical laminar-flow clean rooms. The Integrated Circuit Facility has continued to expand its role in the development of prototype hybrid integrated circuit design and fabrication, and in the necessary research and development to support advanced materials processing and fabrication.

J. F. Hutzenlaub
Head, Division 7

DIVISION 7 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1968

PUBLISHED REPORTS

<u>Technical Notes</u>				<u>DDC and Hayden Nos.</u>
TN No.				
1968-13	Thick Film Layout Considerations	R. E. McMahon H. H. Pichler	12 April 1968	DDC 670573 H-884
1968-17	Pressure Distributions on Sphere-Cone Radomes in Uniform and Gradient Flows	R. D'Amato W. R. Fanning	2 May 1968	DDC 670168 H-883

MECHANICAL ENGINEERING GROUP 71

I. HAYSTACK CRYOGENICS

During this reporting period, the two dewars for the dual maser units were received from the Janis Manufacturing Company. These units will enable two masers of the Haystack receiver to operate simultaneously in the same liquid helium reservoir. Both dewars appear to be vacuum tight at liquid nitrogen and liquid helium temperatures. Boil-off measurements have been made on both units without any heat load into the liquid helium reservoir, and they hold 10 liters of liquid helium for over 40 hours. This indicates that the dual masers will operate in excess of the required 8 hours. During the next quarterly period, it is anticipated that the masers will be evaluated in the PR Box on the ground.

II. SOLID STATE RESEARCH

A. Slow Rate Crystal Puller

To date, hundreds of techniques have been developed for the synthesis of crystals. As numerous as these are, all can be categorized by three basic processes: (1) solidification of the actual components of the material to be grown; (2) crystallization from solution; (3) growth from vapors.

With the presently designed equipment, a variation on the first process is obtained by which a relatively cool rod or a single crystal "seed" is lowered into a melt held exactly at the melting temperature. The seed is then withdrawn slowly so that the melt at the growth-interface is frozen and pulled from the solution.

Activation of growth is accomplished by shaft rotation at a rate of one rotation per day and/or by shock pulses. Mechanical pulsing devices were tried, but with poor results. Experiments still yield polycrystalline materials, probably because of the horizontal wave motion actuated by the mechanical pulse devices. Solenoid pulsing techniques and a new shaft support with magnetic bearings are now being designed.

B. Pressure-Temperature Quench Bomb

The effect of pressure and temperature on materials can sometimes be preserved by sudden cooling. To accomplish this, a technique has been developed by which materials are heated to 1000°C at a pressure of 30,000 psi, after which they are quenched without changing the pressure conditions. The reaction vessel is a two-stage device, one part of which is heated over a furnace while the other half is cooled. Quenching is accomplished by rotating the vessel so that the contents are gravity fed into the cold zone.

III. CO₂ LASER RADAR

Designs for the three pedestals supporting mirror mounts at the Millstone Hill laser installation are 75 percent complete. The two fixed-mirror mounts are completely designed; one

Division 7

will be located at ground level inside the base of the old concrete gun mount, and the other will be directly overhead at the tower rim. The third pedestal, supporting the tracking mirror, is also positioned on the top rim of the tower diametrically opposite the second pedestal. The declination axis of this tracking-mirror pedestal has been designed, and detail design of the elevation axis is under way. In addition, the weldments for the two upper pedestal bases have been completed and have been finish machined.

The two identical fixed-mirror mounts now being fabricated have provision for manual adjustment in declination and elevation, for the purpose of alignment during the initial installation period. The mount to be installed at the foot of the tower will also have provision for auto-collimating by moving the plane of its mirror into a vertical position.

Television tracking of targets is being designed into the system by using a camera which looks into an auxiliary mirror aligned with the tracking mirror and the first fixed mirror of the main system. In order for the viewer to maintain the proper horizontal and vertical references, it will be necessary to drive the TV camera as a function of the elevation and declination axes of the tracking mirror. Design of the camera drive mechanism is in the preliminary stage.

Layout of the various lasers and associated optical equipment has been completed. All units will be mounted on granite tables supported on concrete piers which are anchored to bedrock within the laser building.

Fabrication of the table supports as well as the laser beam expander is nearing completion.

COMPONENT DESIGN AND DEVELOPMENT GROUP 73

INTEGRATED CIRCUIT FACILITY

Computer-Aided Design:— Progress in computer-aided circuit analysis and layout continues to improve the turn-around time for integrated circuit fabrication. The automated layout and mask-making techniques using TX-2 programs and the D. W. Mann pattern generator have additionally begun to influence the direction of the integrated circuit program because of the greater availability of masks and the simplicity of making complex patterns.

The CIRCUS program (circuit analysis) has been partially converted to double precision during the past quarter, and the entire program is now under conversion to double precision. Several other improvements have been made to the program by other companies who acquired CIRCUS from us, and these additions are being implemented as they are received.

Semiconductor Area:— The semiconductor area has progressed satisfactorily with about 50 percent of the total equipment installed in a temporary area and, since most of the utilities and services are available, start-up is expected during the next quarter. During the initial equipment setup period, work has been performed on several projects related to semiconductors. For example, the beam lead substrate approach has proved to be successful and is currently being expanded to double-layer metallization, a forerunner of MSI. This work has been performed in conjunction with the thin-film area which has supplied dielectric and metallization layers.

In addition, the yield of the high power multivaractor package has been increased by using the Mesa processing techniques to recover contaminated varactors. Recent results using this technique with very high frequency varactors indicated no degradation of the 160-GHz cutoff frequency.

Thin- and Thick-Film Areas:— Recent equipment modifications and installations have led to improvements in sputtering and metallization. For example, the CVC triode RF sputtering system was replaced by an MRC sputtering module borrowed temporarily from the National Magnet Laboratory at M.I.T. This provided better control of deposition parameters and conditions, and resulted in immediate improvements in film quality.

In addition, the Veeco unit is being modified to evaporate to an overhead substrate for greater cleanliness. The substrate can be either heated or water-cooled, and will be shielded by a shutter. The source will be either a tungsten coil — as is done now — or a variety of resistance- and ultimately inductance-heated crucibles.

The current installation of an NRC Electron Beam Evaporator will allow, during a single run, evaporation from four E-beam sources and ten resistance-heated sources onto any combination of twenty substrates and masks. Thus, materials of differing sheet resistivity can be put down in one run by evaporating from a number of sources and using an equal number of masks. For example, using the E-beam sources, four materials could be evaporated through different masks and this could be done on sixteen different substrates in one run. The addition of this unit will greatly improve our ability in applications such as microwave attenuators where resistors of similar physical size but greatly different resistance are required.

Division 7

Development efforts during this past quarter have been directed primarily at improving the quality of dielectric and metal films.

Initially, sputtered SiO_2 films were characterized by rapid etch rates, porosity, poor adherence, and cracking. These problems have been overcome by careful control of deposition parameters. Further work in this area is necessary, for example: supplementary etch rate measurements with IR, index of refraction, capacitance vs voltage, dielectric loss and stress measurements.

Highly adherent films of aluminum have been produced by RF sputtering and seem to be characterized by low pinhole density. This latter fact could be of importance where fine line patterns are required. The superconductivity properties of these films are being evaluated at the National Magnet Laboratory.

A technique for evaporating extremely adherent and relatively thick (>1 micron) aluminum films on glass substrates has been adapted for use in the Veeco metallizing system. The glass substrate is outgassed at 300°C in a vacuum of less than 5×10^{-6} torr, cooled to 250°C , and a flash of aluminum is deposited from a tungsten coil source. Finally, the substrate is cooled at 150°C , and aluminum is deposited from one or more sources to the desired thickness.

Tantalum resistor test patterns have been sputtered in both argon straight from the tank and argon prepared by passing it over titanium chips at 800°C . Preliminary results indicate that there are sufficient reactive impurities (O_2 , N_2 , H_2O , etc.) in the tank argon to partially stabilize the tantalum resistors. Thus, care is indicated in the handling of argon to insure reproducibility for both plain and reactive sputtering.

Service to other groups during this reporting period has increased, and several examples are included here to illustrate the character of the work.

Fine line interdigital surface wave transducers have been provided on quartz and sodium potassium niobate substrates. The former operated satisfactorily at 220 MHz; the latter has not yet been tested.

Fabrication of a diode selection matrix involves the bonding of several hundred diode chips to pads on a glass plate magnetic memory device and connecting strips of them across the top sides. Processing is constrained by an upper temperature limit of 200°C . Several areas of capability of the group have been brought to bear on this work from the screening of solder resist, to plating, etching, sputtering, and bonding techniques. Several approaches have proven to be unworkable or too expensive. The current approach calls for a combination of silver epoxy and stitch bonding.

A microwave problem requires the deposition of high quality SiO_2 over capacitor and micro-line patterns on alumina substrates. Thus far, the SiO_2 provided appears to be low loss.

A project has been initiated for Division 4, Radar, to develop microwave strip line and strip line attenuators using both thin- and thick-film techniques. Thin-film attenuators have been delivered for evaluation. These circuits utilize gold and tantalum resistors of a single sheet resistivity trimmed to the desired value. Thick-film transmission lines and resistors are being prepared for evaluation in microwave circuitry.

Other applications of the research and development effort to prototype integrated circuits have been numerous and varied. The crossover and capacitor dielectric thick-film material has been applied to several large circuits, and special bonding techniques including beam lead substrates have been used for microwave, digital, and linear applications.

PHYSICAL PLANT ENGINEERING GROUP 75

I. BUILDING E EXTENSION (Integrated Circuit Facility)

A new addition is currently under construction on the north side of Building E. The bulk of the addition will house a portion of the Laboratory's Integrated Circuit Facility, with the remaining areas housing building services.

The new addition is approximately 56 feet wide by 200 feet long, running the full length of Building E with the main floor matching the existing floor grade. It will have a full length basement, approximately 30 feet in depth.

The integrated circuit space is all on the main floor and is devoted to circuit design and layout, assembly, testing, electronic shops, as well as packaging and plating areas. There will be two clean rooms, a 1000-square-foot class 100 vertical laminar-flow room, and a 1500-square-foot class 10,000 vertical-flow room. Over and above the usual building services, these areas will be served with secondary cooling systems, toxic exhausts, clean compressed air, a vacuum cleaning system, acid drainage, and varying amounts of environmental control, including temperature and humidity. Vibration and sound attenuation are also part of the total environment.

The basement will house the mechanical equipments necessary for the first floor laboratories, two storage bays, an electrical substation, the waste disposal equipment, and future emergency generator space.

Construction of the shell began approximately 1 June 1968, with completion scheduled for 1 February 1969.

II. BUILDING J MODIFICATIONS

Phase I of the program to upgrade and expand the computer facilities in Building J is complete. This work consisted of a major revision of the air-conditioning system to accommodate the increased computer load, and the installation of an automatic sprinkler system for fire protection.

Phase II, consisting of a 6000-square-foot integrated addition to the existing building, commenced on 15 June. Foundation walls are now nearly complete. The entire project, incorporating the same environmental and protective features of Phase I, is scheduled for completion in mid-October.

CONTROL SYSTEMS GROUP 76

I. HAYSTACK

A hydraulic motor with positive piston control is being acquired in order to evaluate its suitability as a replacement for the Haystack antenna power drives. Extensive test stand investigation of the motor characteristics and its compatibility to the new variable displacement control pump is planned.

II. MILLSTONE OPTICAL TRACKER COMPLEX (CO₂ Laser Radar)

Installation of the improved Nike-Ajax mount control system was completed. This involved extensive modifications to the original servo concept, elimination of various subsystems, and fabrication of a new control console. The original vacuum tube design was replaced with solid state circuitry wherever feasible. Improved performance and more convenient operation have been demonstrated.

Design efforts on the overall Millstone optical tracker complex control system continued. Group 76 has responsibility for defining the computer operations required in pointing, indication, and control; for designing and manufacturing the logic required to read information into and out of the computer; for designing and manufacturing the laser tracker servos; and for designing and manufacturing the system control consoles. In addition, the Group has assumed responsibility for interconnecting the wiring among all units at the complex.

SOLID STATE DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 May through 31 July 1968. A more detailed presentation is covered by the Solid State Research Report for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head

DIVISION 8 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1968

PUBLISHED REPORTS

<u>Journal Articles*</u>			
JA No.			
3134A	Epitaxial Gallium Arsenide for High-Efficiency Gunn Oscillators	C. M. Wolfe A. G. Foyt W. T. Lindley	Electrochem. Technol. <u>6</u> , 208 (1968)
3149	Magnon-Phonon Coupling in Metallic Films	R. Weber	Phys. Rev. <u>169</u> , 451 (1968)
3162	Design and Short-Term Stability of Single-Frequency CO ₂ Lasers	C. Freed	IEEE J. Quant. Electron. <u>QE-4</u> , 404 (1968)
3169	Intense Mercury-Vapor Green-Band Emission	R. J. Carbone M. M. Litvak	J. Appl. Phys. <u>39</u> , 2413 (1968)
3186	Light Scattering from Single-Particle Electron Excitations in Semiconductors	A. Mooradian	Phys. Rev. Letters <u>20</u> , 1102 (1968), DDC 671287
3192	Spin-Orbit-Coupling Effects in Transition-Metal Compounds	J. B. Goodenough	Phys. Rev. <u>171</u> , 466 (1968)
3218	Band Model for Transition-Metal Chalcogenides Having Layer Structures with Occupied Trigonal-Bipyramidal Sites	J. B. Goodenough	Materials Res. Bull. <u>3</u> , 409 (1968), DDC 671274
3220	Type Conversion and p-n Junctions in n-CdTe Produced by Ion Implantation	J. P. Donnelly A. G. Foyt E. D. Hinkley W. T. Lindley J. O. Dimmock	Appl. Phys. Letters <u>12</u> , 303 (1968)
3240	Long-Wavelength Infrared Pb _{1-x} Sn _x Te Diode Lasers	J. F. Butler T. C. Harman	Appl. Phys. Letters <u>12</u> , 347 (1968)
3249	Effect of Pressure on the Structure and Magnetic Properties of RbNiF ₃	J. A. Kafalas J. M. Longo	Materials Res. Bull. <u>3</u> , 501 (1968)
3256	Location of Electron and Hole Carriers in Graphite from Laser Magnetoreflexion Data	P. R. Schroeder † M. S. Dresselhaus A. Javan †	Phys. Rev. Letters <u>20</u> , 1292 (1968)

* Reprints available.

† Author not at Lincoln Laboratory.

Division 8

JA No.

- | | | | |
|------|---|--|--|
| 3260 | Band Antiferromagnetism and the New Perovskite CaCrO_3 | J. B. Goodenough
J. M. Longo
J. A. Kafalas | Materials Res. Bull. <u>3</u> , 471 (1968) |
| 3266 | Growth of CdSe Single Crystals by Temperature Gradient Solution Zoning in Excess Se | J. M. Steininger | Materials Res. Bull. <u>3</u> , 595 (1968) |
| 3270 | Microwave Acoustic Amplification in n-InSb at 9GHz | K. W. Nill | Phys. Rev. Letters <u>21</u> , 82 (1968) |

* * . * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.

- | | | | |
|------|---|---|--|
| 3210 | Si-Te System: Partial Pressures of Te_2 and SiTe and Thermodynamic Properties from Optical Density of the Vapor Phase | R. F. Brebrick | Accepted by J. Chem. Phys. |
| 3255 | Intermediate Coupling Polaron Effective Mass | D. M. Larsen | Accepted by Phys. Rev. |
| 3273 | Optical Heterodyne Detection at $10.6\mu\text{m}$ of the Beat Frequency Between a Tunable $\text{Pb}_{0.88}\text{Sn}_{0.12}\text{Te}$ Diode Laser and a CO_2 Gas Laser | E. D. Hinkley
T. C. Harman
C. Freed | Accepted by Appl. Phys. Letters |
| 3274 | Magnetic Resonance | R. Weber | Accepted by <u>Magnetism and Magnetic Materials 1968 Digest</u> (Academic Press, New York) |
| 3275 | Descriptions of Outer d Electrons in Thiospinels | J. B. Goodenough | Accepted by J. Phys. Chem. Solids |
| 3276 | Far Infrared Photoconductivity in High Purity Epitaxial GaAs | G. E. Stillman
C. M. Wolfe
I. Melngailis
C. D. Parker
P. E. Tannenwald
J. O. Dimmock | Accepted by Appl. Phys. Letters |
| 3280 | Pressure-Induced Structural Changes in the System $\text{Ba}_{1-x}\text{Sr}_x\text{RuO}_3$ | J. M. Longo
J. A. Kafalas | Accepted by Materials Res. Bull. |
| 3284 | Non-Metals | N. Menyuk | Accepted by <u>Magnetism and Magnetic Materials 1968 Digest</u> (Academic Press, New York) |

JA No.

- | | | | |
|------|--|-------------------------------|----------------------------------|
| 3296 | Photoconductivity in Single-Crystal $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$ | I. Melngailis
T. C. Harman | Accepted by Appl. Phys. Letters |
| 3303 | Quenchable Effects of High Pressures and Temperatures on the Cubic Monoxide of Titanium | M. D. Banus | Accepted by Materials Res. Bull. |
| 3316 | Preparation of $\{\text{A}_3^{2+}\}[\text{Te}_2](\text{B}_3^{2+})\text{O}_{12}$ -Garnets | H. M. Kasper | Accepted by Materials Res. Bull. |

Meeting Speeches*

MS No.

- | | | | |
|-----------------|---|---|--|
| 1719G,
1719H | Interstellar OH Maser Emission | M. M. Litvak | Seminar, M.I.T., 24 May 1968;
Seminar, M.I.T., 14 June 1968 |
| 1793B | Polaron Self-Energy Effects in InSb | E. J. Johnson | Seminar, Brown University,
17 July 1968 |
| 1882E | Raman Scattering from Elementary Excitations in Solids Using Lasers | A. Mooradian | Seminar, Brown University,
26 June 1968 |
| 1954B | Localized vs Collective Descriptions of Magnetic Electrons | J. B. Goodenough | Seminar, Westinghouse Research Laboratory, Pittsburgh, Pennsylvania, 16 May 1968 |
| 2141C | Magneto-Optical Studies of Some Narrow-Gap Semiconductors | S. H. Groves | Seminar, Thomas J. Watson Research Center, Yorktown Heights, New York, 23 May 1968 |
| 2166A | Electronic Raman Scattering from Impurities in Semiconductors | G. B. Wright
A. Mooradian | } 9th International Conference on the Physics of Semiconductors, Moscow, 23 - 29 July 1968 |
| 2182 | Fourier Expansion for the Deformation Potential in the Diamond Lattice | G. F. Dresselhaus
M. S. Dresselhaus | |
| 2183 | Interband Magnetoreflexion of Gray Tin | S. H. Groves
C. R. Pidgeon†
A. W. Ewald†
R. J. Wagner† | |
| 2188 | Electroreflexion Study of Inversion Asymmetry and Warping Induced Interband Magneto-Optical Transitions in InSb | C. R. Pidgeon†
S. H. Groves | |

* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

† Author not at Lincoln Laboratory.

Division 8

MS No.

2195	An Exciton in a High Magnetic Field — Germanium	E. J. Johnson	} 9th International Conference on the Physics of Semiconductors, Moscow, 23 — 29 July 1968
2291	Fourier Expansions for Dispersion Relations in Semiconductors	G. F. Dresselhaus	
2210A	Finite Temperature Single-Determinant Theory	T. A. Kaplan	Seminar, Purdue University, 17 May 1968
2216	Thermal Blooming and Instability of Light Beams Due to Absorption	N. M. Kroll* P. L. Kelley	} International Quantum Electronics Conference, Miami, Florida, 14 — 17 May 1968
2219	New Experimental Features of Thermal Defocusing of Laser Light in Liquids	R. L. Carman P. L. Kelley	
2221	Influence of the Molecular Interaction on the AC Kerr Effect: Possibility of a Field-Induced Phase Transition	J. Hanus	
2222	The Evolution of Intense Quasi-Monochromatic Light Pulses in Dispersive Nonlinear Optical Media	T. K. Gustafson* H. A. Haus* J-P. Taran* P. L. Kelley	
2262	Self-Steepening and Spectral Broadening of Intense Laser Light	P. L. Kelley	
2216A	Thermal Blooming and Instability of Light Beams Due to Absorption	P. L. Kelley	Seminar, United Aircraft Corporation, Hartford, Connecticut, 27 May 1968
2261A	d-Bands in Transition Metals and Oxides	J. Feinleib	Seminar, University of Chicago, 4 June 1968
2304	Laser Action and Photodetection in Lead-Tin Chalcogenides	I. Melngailis	} International Colloquium on IV-VI Compounds, Paris, 15 — 18 July 1968
2349	Deviations from Stoichiometry and Lattice Defects in IV-VI Compounds and Their Alloys	A. J. Strauss R. F. Brebrick	
2307	Diffusion and Convection in Vapor Crystal Growth	T. B. Reed W. J. LaFleur A. J. Strauss	International Conference on Crystal Growth, Birmingham, England, 15 — 19 July 1968
2310	Long-Wavelength Infrared Diode Lasers of Bismuth-Doped $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$	J. F. Butler T. C. Harman	Solid State Device Research Conference, University of Colorado, 17 — 19 June 1968

* Author not at Lincoln Laboratory.

MS No.

2317	Photoresponse of $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$ Detectors	A. R. Calawa I. Melngailis T. C. Harman	Solid State Device Research Conference, University of Colorado, 17 - 19 June 1968
2318	Isolation of Junction Devices in GaAs Using Proton Radiation Damage	A. G. Foyt W. T. Lindley J. P. Donnelly C. M. Wolfe	
2319	GaAs Schottky Barrier Photodiode with High Gain	W. T. Lindley R. J. Phelan, Jr. C. M. Wolfe	
2320	Far Infrared Photoconductivity in High Purity Epitaxial GaAs	G. E. Stillman C. M. Wolfe I. Melngailis C. D. Parker P. E. Tannenwald J. O. Dimmock	
2322A	Optical Heterodyne Detection of the Beat Frequency Between a Tunable Diode Laser and a CO_2 Laser	E. D. Hinkley	Seminar, M.I.T., 9 July 1968
2324	Polarons in Indium Antimonide	D. M. Larsen	Seminar, Northeastern University, 7 May 1968
2336	Light Scattering from Plasma Waves in Solids	A. L. McWhorter	International Advanced Summer Physics Institute, Chania, Crete, Greece, 1 - 12 July 1968
2337	Comparison of the Theoretical O^{2-} Form Factors with Experiment	P. M. Raccach R. J. Arnott	
2338	Meaning of an Anomaly in the X-Ray Scattering of ZnSe	P. M. Raccach R. J. Arnott A. Wold*	
2339	Band Approach to the Transition Metal Oxides	J. Feinleib	
2342	Spherical Model as the Limit of Infinite Spin Dimensionality	H. E. Stanley	Banff Seminar on Critical Phenomena, Banff, Canada, 11 - 30 August 1968
2347	Exciton and Polaron Structure in the Fundamental Absorption of Semiconductors	E. J. Johnson	Seminar, General Motors Corporation, Warren, Michigan, 14 June 1968

* Author not at Lincoln Laboratory.

SOLID STATE DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Infrared radiation in the wavelength region between 300 and 1000 μ has been modulated utilizing free carrier absorption by impact ionized electrons in germanium. Modulation depths of up to 20 percent at 902 μ and several percent at 337 μ have been observed with time constants less than 0.1 μ sec.

Guard rings consisting of epitaxial n-GaAs have been grown for GaAs p-n junction and Schottky barrier avalanche diodes utilizing the AsCl_3 -Ga- H_2 flow system. The breakdown voltage for the guarded structures is higher than for those without a guard ring, and in avalanche breakdown light is emitted nearly uniformly across the diode, whereas in unguarded diodes light emission is at the perimeter. The guarded diodes have been used as avalanche photodetectors and show a gain in excess of 100 when biased near reverse breakdown.

The combined effects of applied DC bias and short wavelength radiation on the properties of InSb-MOS infrared detectors have been further investigated. Several processes have been isolated and identified. For photon energies greater than 0.5 to 2.0 eV, depending upon the initial charge state of the system, electrons are photoemitted from the InSb into the oxide where they may become trapped. For photon energies greater than 1.0 to 3.0 eV, again depending upon the initial charge state of the system, the oxide layer becomes photoconductive. These effects are reflected in the response of the InSb-MOS detector to 3.9- μ InAs diode radiation and appear to be a controlling factor in the performance of the device.

High-resistivity surface layers up to 4 μ deep have been produced in 4 ohm-cm p-type ZnTe by bombardment with approximately 10^{14} protons/cm² from a 400-kV Van de Graaff generator. Contact-to-contact resistance between ohmic contacts on the front surface increased from about 200 ohms to greater than 10^9 ohms after bombardment.

A study of metal inclusions and low-angle grain boundaries in $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$ crystals has indicated that these defects are due to constitutional supercooling during growth. This explanation indicates that these defects may be avoided by growing from a sufficiently tellurium rich melt, by growing in a steep temperature gradient, or by decreasing the growth rate. Crystals grown from a $(\text{Pb}_{1-x}\text{Sn}_x)_{0.49}\text{Te}_{0.51}$ melt have been found to be essentially free of these macroscopic defects.

The properties of bismuth-doped $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$ diode lasers have been examined for x in the range $0.24 \lesssim x \lesssim 0.27$, where it is difficult to obtain high carrier concentration n-type material by deviations from stoichiometry only. The main effect of doping with Bi is believed to be a shift in the composition at which n = p to the Te-rich side of the stoichiometric line. This allows larger n-type carrier concentrations to be obtained with shorter annealing times. The Bi doping also reduces the laser threshold current densities at both 12° and 77°K. In fact, at 77°K, undoped diodes in this composition range did not exhibit laser emission up to 30,000 A/cm², while doped diodes had threshold currents between 1000 and 5000 A/cm².

II. OPTICAL TECHNIQUES AND DEVICES

A 9-meter CO_2 amplifier with an average bore of 25 mm has yielded a small signal gain of 4.8 db/meter. This gain was for a sealed-off gas mixture and compares favorably with the measured gain of a flowing gas amplifier.

The usefulness of the f-number criterion for the achievement of optimum "optical" heterodyning has been demonstrated experimentally.

Some preliminary propagation measurements and calculations at $10\text{ }\mu\text{m}$ are being made in anticipation of the requirements and capabilities of the Millstone Hill CO_2 laser radar.

Variation of the refractive index with temperature enables continuous tuning of the $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$ diode laser. Beat frequencies from essentially zero to 3.5 GHz have been observed in heterodyne experiments using the P_{18} , P_{20} , and P_{22} lines from a CO_2 laser. Preliminary observations were made of the Lorentzian-shaped laser line profile. Also measured was the frequency response of a Ge:Cu detector similar to one scheduled for use in the CO_2 Doppler radar system.

III. MATERIALS RESEARCH

A number of garnets containing tellurium, with the type formula $\{\text{A}_3\}[\text{Te}_2](\text{B}_3)\text{O}_{12}$, have been prepared by sintering stoichiometric mixtures of oxides and carbonates. They include the first garnets in which Co^{+2} ions occupy only tetrahedral sites and a series of rare-earth garnets in which B is Li^+ and A is triply charged Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, or Lu.

The atmospheric pressure phase of CdCr_2Se_4 , which has the cubic spinel structure, is transformed at high pressures and elevated temperatures into a phase with the monoclinic defect-NiAs structure. In contrast with the spinel phase, which is a ferromagnetic semiconductor, the high-pressure phase is metallic and nonmagnetic.

A high-pressure form of CsNiF_3 has been prepared by reaction of CsF and NiF_2 at 65 kbars and 700°C . This phase has a hexagonal structure isomorphous with that of the atmospheric pressure phase of RbNiF_3 and, like that phase, is a light yellow, transparent ferrimagnet.

The atmospheric pressure phase of SrIrO_3 has been found to have a monoclinic structure closely related to that of the atmospheric pressure phase of RbNiF_3 . At high pressures and elevated temperatures, SrIrO_3 is transformed into a phase with orthorhombically distorted perovskite structure.

An extensive summary of the crystallographic and magnetic properties of perovskite and perovskite-related compounds, with an interpretive introduction and over 1500 references, has been prepared for the Landolt-Bornstein Tabellen.

The low-lying energy levels of U^{+3} compensated by Na^{+1} in $\text{CaF}_2:\text{NaUF}_4$ have been determined by infrared absorption measurements. Because of the high proportion (90 percent) of orthorhombic site symmetry and the relatively high energy (607 cm^{-1}) of the terminal level for laser emission, the threshold for pulsed laser action in this material is less than 1 joule at 77°K .

A method has been developed for the analysis of Zn-Te-Se alloys which is accurate to within a few parts per thousand for each component. The Se and Te are determined by classical oxidation-reduction methods using automatic titration equipment, and Zn is determined by an x-ray fluorescence method.

IV. PHYSICS OF SOLIDS

Recent optical and transport data for NiO indicate that the localized crystal-field spectrum and the band-like, nonactivated mobility are incompatible properties if only d-electrons are considered; electron band states are also necessary. A procedure is suggested for portraying both these properties on a single diagram, analogous to the band structure diagram of simpler materials.

The study of oscillatory magnetoreflexion in bismuth-antimony alloys at low temperatures indicates an increase of energy gap and effective mass with increasing antimony concentration in the range of composition $0 \lesssim \% \text{ Sb} \lesssim 15$. In contrast with the semimetallic nature of bismuth, the higher antimony alloys exhibit the semiconducting behavior suggested by transport measurements.

Using a generalization of a method developed by P. Resibois for a pure interacting Fermi gas, the transport properties for weak and slowly varying disturbances have been investigated. Coefficients of the transport equation have been calculated for (a) a neutral or charged Fermi liquid in the presence of random impurities, (b) dynamically independent fermions in the presence of dilute but arbitrarily strong impurity scattering centers, and (c) a Fermi liquid in the generalized random phase approximation in the presence of dilute, but arbitrarily strong impurity scattering centers.

Measurements of the magnetic properties of MnAs under pressure have been extended to include paramagnetic susceptibility in the high-temperature $B8_1$ phase. It was found that, unless third-order strain effects are included, even a generalized form of the Bean-Rodbell thermodynamic theory is unable to explain the change in sign at the hexagonal-orthorhombic transition of the pressure dependence of the paramagnetic Curie temperature. The fact that this sign change is restricted to a narrow temperature interval is attributed to large changes in the exchange parameters through the narrow transition region where the manganese atomic moment is changing from a high- to a low-spin value.

The high-temperature expansion method, applied to the Heisenberg model, has been used to investigate the dependence of the zero-field susceptibility exponent on spin quantum number in ferromagnets, and to compare the exponent of the staggered susceptibility of two- and three-dimensional antiferromagnets with other recent work. An exact solution for a linear chain of isotropically interacting classical spins of arbitrary dimensionality has been obtained.

Preliminary experiments of light scattering from ferromagnetic CrBr_3 and ferromagnetic RbNiF_3 have been carried out with an argon ion laser. Both elastic (Rayleigh) scattering near the transition temperature and inelastic (Raman) scattering over a wider temperature range are being investigated.

An attempt has been made to measure by high resolution Raman scattering at liquid helium temperatures the splitting, $\Delta\omega = \omega_L - \omega_T$, of the 128-cm^{-1} Raman vibration in quartz. Even at 5°K , the linewidth ($\delta\omega = 0.05 \pm 0.01\text{ cm}^{-1}$) is about twice the gap ($\Delta\omega = 0.02 \pm 0.01\text{ cm}^{-1}$); thus, the doublet was not resolved.

DOCUMENT CONTROL DATA - R&D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author)		2a. REPORT SECURITY CLASSIFICATION
Lincoln Laboratory, M.I.T.		Unclassified
		2b. GROUP
		None
3. REPORT TITLE		
Quarterly Technical Summary on General Research		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)		
Quarterly Technical Summary for 1 May through 31 July 1968		
5. AUTHOR(S) (Last name, first name, initial)		
Frick, Frederick C.	Dodd, Stephen H.	Freedman, Jerome
Nedzel, V. Alexander	Herlin, Melvin A.	Weiss, Herbert G.
		Hutzenlaub, John F.
		McWhorter, Alan L.
		Tannenwald, Peter E.
6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
15 August 1968	52	3
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)	
AF 19(628)-5167	General Research QTS	
b. PROJECT NO.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
649L	ESD-TR-68-232	
c.		
d.		
10. AVAILABILITY/LIMITATION NOTICES		
This document has been approved for public release and sale; its distribution is unlimited.		
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY
None		Air Force Systems Command, USAF
13. ABSTRACT		
<p>This Quarterly Technical Summary covers the period from 1 May through 31 July 1968. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.</p>		
14. KEY WORDS		
data systems	control research	microwave equipment
digital computers	radio physics	mechanical and structural engineering
computer components	space surveillance	solid state physics
psychology	radar	